DTU Library

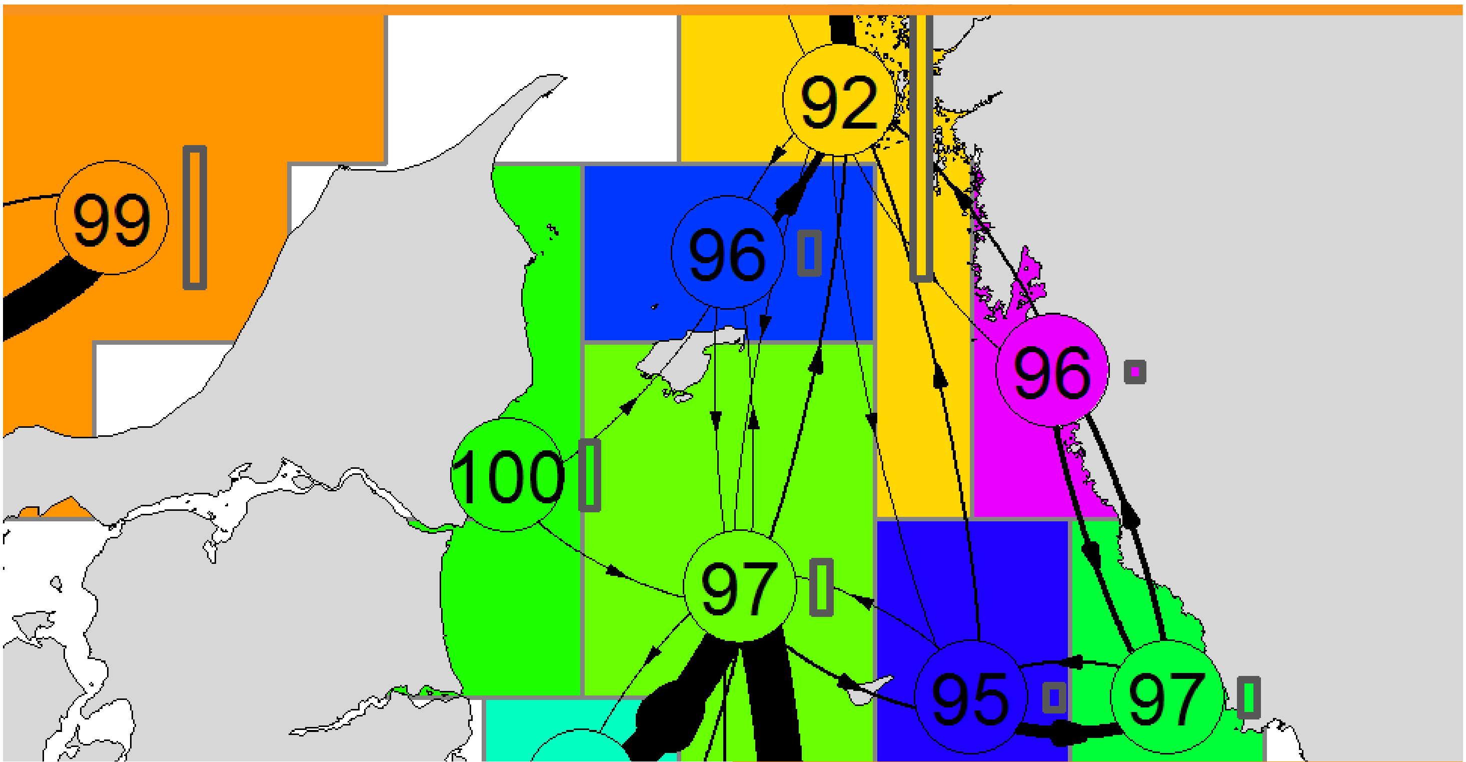
Same Risk Area Case-study for Kattegat and Øresund. Final report

Hansen, Flemming Thorbjørn; Christensen, Asbjørn

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Same Risk Area Case-study for Kattegat and Øresund
Final report



DTU Aqua report no. 335-2018
By Flemming Thorbjørn Hansen
and Asbjørn Christensen

DTU Aqua
National Institute of Aquatic Resources

Same Risk Area Case-study for Kattegat and Øresund
Final report

DTU Aqua report no. 335-2018

Flemming Thorbjørn Hansen and Asbjørn Christensen

DTU Aqua
National Institute of Aquatic Resources

Title:	Same-Risk-Area Case-study for Kattegat and Øresund. Final report.
Authors:	Flemming Thorbjørn Hansen and Asbjørn Christensen
DTU Aqua report no.:	335-2018
Year:	November 2018
Reference:	Hansen, F. T. & Christensen, A. (2018). Same-Risk-Area Case-study for Kattegat and Øresund. Final report. DTU Aqua report no. 335-2018. National Institute of Aquatic Resources, Technical University of Denmark. 37 pp. + appendicies.
Cover:	Example from the SRAMM-tool of hydrographic regions identified for *Didemnum vexillum* based on 3 years larval dispersal simulation.
Copyright:	Total or partial reproduction of this publication is authorised provided the source is acknowledged
Published by:	National Institute for Aquatic Resources, Kemitorvet, 2800 Kgs. Lyngby, Denmark
Download:	www.aqua.dtu.dk/publications
ISSN:	1395-8216
ISBN:	978-87-7481-254-8

Preface

This study was funded by the Danish fund “Aktieselskabet Dampskibsselskabet Orient's Fond”, Danish Ferries and Stena Line Group. We want to express our gratitude to the external advisory group for their interest and engagement. The advisory group included Ulrich Christian Berggreen and Kim Larsen (Danish Environmental Agency), Clea Henrichsen (Maritime Authority of Denmark), Per Winther Christensen (Danish Ferries & Danish Shipping), Frank Stuer-Lauridsen (Litehauz Aps) and Karen Edelvang (DTU Aqua). We also want to thank a number of representatives from stakeholders that were invited to participate in the advisory group meetings and workshops including Erland Lettevall (Swedish Agency for Marine and Water Management), Henrik Ramstedt (Swedish Agency of Transport), Fredrik Larsson (Swedish Ship Owners Association), Johan Roos (Interferry), Erik Lewenhaupt and Cecilia Andersson (Stena Line Group) and Katja Broeg (Bundesamt für Seeschifffahrt und Hydrographie). A special thanks to Frank Stuer-Lauridsen (Litehauz Aps) for organising project workshops and advisory group meeting, and for valuable discussions and contribution to the work process during the course of the study. Finally we want to thank Kathe Jensen (Natural History Museum of Denmark) for reviewing the species target list included in the study.

Kgs. Lyngby, Denmark, November 2018

Flemming Thorbjørn Hansen
Senior Consultant
DTU Aqua

Karen Edelvang
Head of Section
DTU Aqua

Content

1 Introduction

1.1 Background

Invasive species are recognized by the UN as one of the greatest threats to the ecological and the economic well-being of the planet. Numerous examples of detrimental invasions are known globally from both land and the aquatic environment[1]. The steadily increasing volumes of sea-borne trade have caused transport with ships to be identified as a key component in the spread of the problem in the marine environment. In consequence, the International Maritime Organization (IMO) under the UN has adopted the Ballast Water Management Convention (BWMC), which entered into force September 2017.

Marine invasive species (MIS) are marine organisms originating from one part of the world that are introduced into other parts of the world e.g. via biofouling on the ship's hull or with the discharge of ship's ballast water and ballast water sediments into the ambient environment, where they may establish new populations potentially altering the existing marine ecosystems and/or harming fisheries and other economic activities. The aim of the BWMC is to prevent MIS to be spread via ballast water from ships by setting strict discharge standards effectively requiring that ballast water is treated before it is discharged. This means that ship owners in international trade need to install costly treatment technology in each vessel (purchase per ship has been estimated to between US$ 0.5 - 5 mill + maintenance)[2]. The BWMC, however, does provide an opportunity for granting exemptions to ships that operate on specified routes between harbors in 2 or more countries, if a risk assessment shows a low and acceptable risk for transfer of MIS. If an exemption is granted, the ship owner will not need to install ballast water treatment technology in the ship for a period of 5 years, after which an extension of the exemption must be applied for. This time frame is important to notice because there will be costs associated with each application, both for ship owners as well as national authorities.

While the BWMC guidelines G7 (MEPC 2017) describe general procedures for granting exemptions, the HELCOM and OSPAR commissions for the Baltic Sea and the North Sea respectively have developed comprehensive and specific data collection procedures to be applied by the member states (HELCOM and OSPAR 2015). These entail extensive monitoring programs of each harbor and subsections of each harbor to monitor for presence or absence of known MIS including various life stages at least two occasions within a year. The sampling and monitoring program and the risk assessment itself must be financed by the ship owner and the data provided to the authorities.

While monitoring of the presence of invasive species in harbors is an important data source for documenting the introduction and invasion histories of MIS in a risk assessment context, there

[1] "The Ten Most Wanted" http://globallast.imo.org/wp-content/uploads/2015/01/TenMostWanted_English.pdf

[2] According to http://www.ballastwatermanagement.co.uk. Maintenance cost include energy consumptions, spare parts and chemical depending on type of system.

are some limitations and disadvantages. E.g. there is a considerable risk that a monitoring program will fail to identify all MIS present in the harbor especially in the early stages of an introduction (e.g. Trebitz et al. 2017). Failing to identify the full extent of the presence of one or more MIS in the monitored harbors (or in their vicinities) in a monitoring campaign, despite its presence, may result in an undesired risk assessment outcome rejecting an exemption application, which may otherwise have been approved. Novel marine species monitoring approaches using molecular analysis techniques such as e-DNA (Roussel et al. 2015, Goldberg et al. 2016) or proteomics (Ashworth 2017) e.g. using high throughput mass spectrometry, are promising however still being researched. The monitoring of the harbors in many parts of the world may not be practical either because of limited scientific capabilities in conducting such monitoring surveys and species identifications, and costs may be disproportional to the economy of the local ship owners. Finally, the workload of national authorities to evaluate and make decision on BWMC exemption applications from each individual ship owner and operator may be considerable.

The Danish consultancy company Litehauz Aps originally proposed an alternative or supplement to the guidelines developed by HELCOM/OSPAR, to ease the burden for ship owners and to reduce the costs of extensive monitoring programs. This alternative is referred to as a Same Risk Area (SRA) and consists of an area based risk-assessment approach relying on existing data aiming at investigating and providing documentation for the decision granting a general exemption to the BWMC within a well-defined marine area. A general exemption means that ships exclusively operating within the designated area will be allowed to operate without the need to install ballast water treatment technologies. Ships that operate regularly or occasionally to and from an SRA will still need to treat the ballast water as required by the BWMC. The SRA concept has already been adopted by the IMO and explicitly included in the BWMC guideline document G7 (MEPC 2017). The SRA concept has been described by Stuer-Lauridsen et al. (2016) and Stuer-Lauridsen et al. (2018).

The main prerequisite for an SRA is that the risk of natural dispersal of MIS inside an SRA is high, and that the contribution of ballast water-mediated transfer of MIS does not contribute significantly to the overall risk. The rationale is that if the risk of natural dispersal is high, the MIS may disperse within the SRA due to natural processes within a given time frame anyway, and the risk will remain more or less unchanged whether the ballast water is treated or not. In such case an SRA may be considered by the respective national authorities. A low natural dispersal may not automatically imply that an SRA cannot be assigned. But then a low “acceptable risk” needs to be justified for other reasons, and therefore an SRA risk assessment must include additional relevant information. Because natural dispersal is the key parameter of the SRA risk assessment, some sort of estimate of the natural dispersal of MIS is required for supporting decision makers in designation of an SRA.

An estimation or prediction of the natural dispersal of MIS can be done using computational modelling of the natural dispersal of existing and/or expected MIS in the water column in the area investigated. Dispersal modelling of marine organisms requires data on simulated hydrography (~sea currents) and knowledge of the dispersal behavior of the MIS considered. The outcome of dispersal models can be analyzed by the use of different statistical and mathematical techniques to identify areas with high “connectivity” due to the predicted natural dispersal of MIS, and the areas that may act as dispersal barriers where dispersal is limited or non-existing.

The identification of both highly connected areas as well as dispersal barriers will provide a valuable contribution to an area based risk assessment approach as proposed by Stuer-Lauridsen et al. (2016). The premise is that if the predicted natural dispersal in a well-defined marine area is high, it may be reasonable to assume that the contribution to the risk of dispersal MIS within the area via untreated ballast water is insignificant compared to the dispersal of organisms due to natural processes

1.2 Objective

The scope of this study is to apply the SRA concept on a specific area including the Kattegat and Øresund region between Denmark and Sweden. A number of ferry lines operate in this area between the two countries. The main focus of the study is to identify relevant potential and existing MIS in the region and to give a best estimate on the potential natural dispersal of each species as a basis for an area based risk assessment to support the national authorities in a decision on an eventual SRA assignment in the Kattegat and Øresund or parts hereof. The study proposes a rating of each species expressing to which extent the species supports a designation of an SRA in the whole of the Kattegat and Øresund region. If a species is considered to limit the extent of an SRA, this decision will rely not only on the analyses of potential natural dispersal but also include other considerations relevant for a risk assessment. Due to the nature of the problem analyzing the natural dispersal of MIS which have not yet been introduced, or MIS which have been introduced but not yet fully established in the region, the approach will be partly theoretical. A number of assumptions are required for the individual steps of the analysis and these assumptions may affect the outcome of a risk assessment. Thus, the approach we present here is attempted to be as transparent and reproducible as possible so that scientific disagreement on individual assumptions can be relatively easily tested and challenged.

1.3 How to read this report

This main report is meant to be a condensed version of a rather comprehensive study with a large amount of produced data and methodological considerations. The primary focus of this report is to present an overview of the background and of the methodology applied, and the main results from the SRA assessment. For readers interested in the details on methodologies applied and the species specific results, three extensive appendices have been included as extensions to the main report. Appendix 1 presents the selection of MIS included in this study. Appendix 2 presents the main results from the larval dispersal modelling and the connectivity analysis of each species and an interpretation of the connectivity analysis results given available knowledge of the species life history characteristics and recorded invasion histories. Appendix 3 presents additional results from the connectivity analysis supporting the results interpretation in appendix 2.

1.4 Funding

The study has been funded by the Danish fund “Aktieselskabet Dampskibsselskabet Orient's Fond”, the Danish ferry owners association “Danish Ferries”, and the ferry line operator “Stena Line Group”.

1.5 Advisory group

An advisory group has been consulted during the course of the study. The advisory group included Ulrich Christian Berggreen and Kim Larsen (Danish Environmental Agency), Clea Henrichsen (Maritime Authority of Denmark), Per Winther Christensen (Danish Ferries & Danish Shipping), Frank Stuer-Lauridsen (Litehauz Aps) and Karen Edelvang (DTU Aqua).

2 Methodology

2.1 Overview

An initial review has been carried out of existing and potential marine invasive species (MIS) in the Kattegat and Øresund region using available MIS databases and data portals to create a target list of species to be included in the case study. To estimate the natural dispersal of the selected MIS in Kattegat and Øresund, the Same-Risk-Area Assessment Model (SRAAM) is used (described in Hansen and Christensen (2018)). In short, the methodology is based on a Lagrangian approach here referred to as an agent-based model (or ABM) simulating the dispersal of individual organisms (~ here referred to as agents) as a function of ocean current direction and speed predicted by hydrodynamic models. Results from the dispersal modelling in terms of start and end positions of each simulated organism are compiled in a connectivity adjacency matrix, describing the number of agents with an initial position in one sub-area that ends up in any other sub-area. Here, the study area is subdivided into a regular grid, and the number of agent connections is counted between all pairs of subareas (~grid cells) in the study area. The connectivity adjacency matrix is translated into a connectivity probability matrix each value representing the probability that an agent with an initial position in each sub-area will end in any of the other sub-areas. The connectivity probability matrix is then analyzed using clustering techniques to identify clusters of subareas that are well connected and with a high exchange of agents between sub-areas within each cluster, and with limited connection to neighboring clusters (Figure 1). The outline of individual clusters we refer to as hydrographic regions a proposed by Vincent et al. (2014).

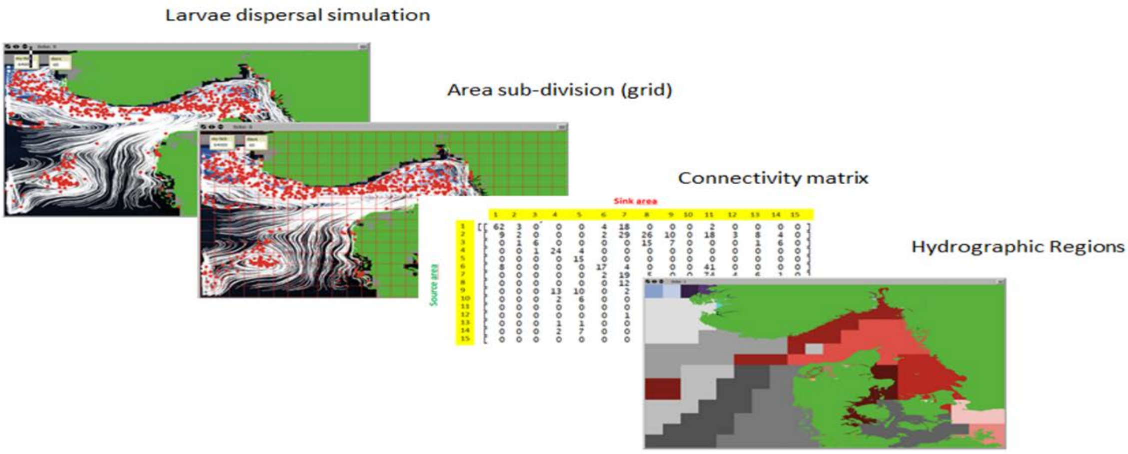


Figure 1. Individual steps supported by the SRAAM tool (from Hansen and Christensen 2018): 1. Dispersal simulation based on existing hydrographic data and biological characteristics of the organism; 2. Area subdivision, - dividing the model domain into a regular grid; 3. Calculation of a connectivity probability matrix; 4. Cluster analysis for dividing the model domain into hydrographic regions representing regions with high connectivity within each region, and low connectivity between regions.

The outline of the hydrographic regions and the measures of strengths of the connectivity within and between hydrographic regions for each species are the main outcome of the analysis and are used as input to a final SRA assessment. The within regions connectivity is also referred to as coherence. The SRA assessment include a thorough interpretation of the connectivity analysis results for each species given available knowledge of the species, including the life history characteristics of the species, recorded invasion histories and other relevant information. Based on this interpretation each species is rated to the extent to which the estimated natural dispersal may be a limitation for assigning an SRA to the whole of the Kattegat and Øresund region. Those species identified as potentially being a limitation for an SRA assignment to Kattegat and Øresund will be further evaluated based on additional information relevant in a risk assessment context.

The individual steps of the applied methodology are shown in Figure 2.

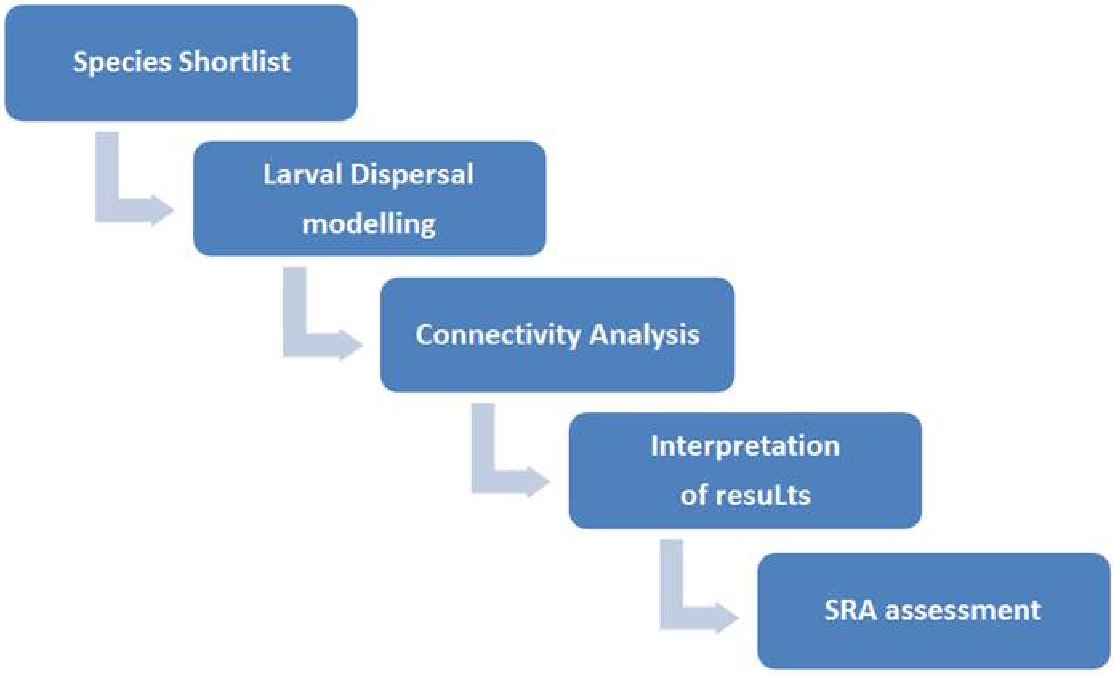


Figure 2. Individual analytical steps applied in the SRA Case Study for Kattegat and Øresund

2.2 Target species

A shortlist of MIS considered in the SRA case study for Kattegat and Øresund was compiled in consultation with the Danish Environmental Protection Agency and based on data from available databases of existing and potential MIS for the Kattegat and Øresund region. The databases include:

- Target species list provided by HELCOM/OSPAR[3]
- Danish Nature Agency (Jensen 2013)
- AQUANIS database[4]

---

[3] HELCOM/OSPAR Ballast Water Exemptions Decision support tool (http://jointbwmexemptions.org)

[4] http://www.corpi.ku.lt/databases/index.php/aquanis/

Species subject to ballast water mediated transport were extracted from the three data sources and only species which have already been registered in the Kattegat and Øresund region or species that have not yet been registered but have been identified as potential MIS in the region were included. This resulted in a preliminary list of 84 species. These species were further examined in more detail considering four criteria. Any species for which at least one of the criteria listed below was fulfilled was removed from the list and not considered for the SRA case study. The four criteria include:

1. Species with the entire life cycle in the water column
2. Species that are already fully established in the Kattegat and Øresund region.
3. Species with no or very limited salinity tolerance < 10 PSU.
4. Macro algae and macrophytes.

Ad 1) Species with the entire life cycle in the water column (e.g. pelagic copepods, pelagic fish, pelagic phytoplankton, jellyfish etc.) are not expected to be a limiting factor for the extent and delineation of an SRA in Kattegat and Øresund compared to species with short pelagic life stages in the order of days or weeks.

Ad 2) Species already introduced to the Kattegat and Øresund region and considered fully established in all suitable habitats throughout the study area, are not a concern to the BWMC.

Ad 3) Freshwater species and species that do not tolerate salinities above 10 PSU are not expected to survive in Kattegat and Øresund region except in local areas receiving freshwater from major rivers.

Ad 4) Most macro algae and macrophytes have limited (~ few meters) dispersal capability of seeds and spores. Shredded thallus however may drift in many month and over vast distances (>100s of km's). This long distance dispersal of thallus (also referred to as "rafting") is unlikely to be a limiting factor for identifying well connected areas and dispersal barriers in the at Kattegat and Øresund region.

A total of 23 species were finally selected, Table 1. For each species data on life history parameters, habitat preferences and environmental tolerances were extracted from MIS data portals, the scientific literature or estimated.

The life-history traits include minimum and maximum recorded pelagic larvae duration (PLD), onset and end of spawning, and the number of generations per year estimated from data on PLD, maturation time and the length of the spawning season . Habitat preferences include preferred seabed substrate divided into four categoreis ("mud", "sand", "hard" and "All types") and distribution depth. Environmental tolerances include minimum and maximum thresholds for salinity and temperature for adults and pelagic larval stages. Common for all species selected is that they have a limited PLD from days to weeks, while most of their life cycle is sessile located on or in the seabed.

In appendix 1 is included the gross list of 84 species from which the short list was created. In addition, the appendix 1 presents an overview of the distribution of species traits among the resulting 23 species in the final shortlist.

Table 1. Shortlist of MIS selected for the Kattegat and Øresund case study, including life history traits and environmental tolerances retrieved or estimated from exiting data-bases and the literature. Values followed by a ' * ' are based on assumptions where no empirical data or descriptions could not be found.

SPECIES	Taxon	PLD (min)	PLD (max)	Generations per year	Spawning start	Spawning end	Habitat Substrate	Habitat Depth	Temp. Min (Adult)	Temp. Max (Adult)	Salinity Min (Adult)	Salinity Max (Adult)	Temp. Min (Larvae)	Temp. Max (Larvae)	Salinity Min (Larvae)	Salinity Max (Larvae)
		days	days	no.s	month	month	type	m	C	C	PSU	PSU	C	C	PSU	PSU
Arcuatula senhousia	Mollusca	14	55	1	7	8	All	20	0	33	17	35	22.5	30	17	30
Asterias amurensis	Echinodermata	41	120	1	6	10	All	220	0	25	18	41	17	20	18	41
Austrominius modestus	Crustacea	10	15	1	5	10	Hard	5	0	26	14	40	6	25	25	32
Bugula neritina	Bryozoan	0.5	2	1	7	9	Hard	10	0	25	18	30	12	26	14	32
Bugulina simplex	Bryozoan	1	1	1	7	9	Hard	20	0	25	18	40	?	25	18	40
Callinectes sapidus	Crustacea	31	49	1	5	8	Mud, Sand	36	5	30	3	40	15	25	20	40
Crassostrea gigas	Mollusca	21	28	1	7	8	Hard	15	3	35	12	42	18	26	10	42
Didemnum vexillum	Tunicata	0.5	1	1	7	9	Hard	65	2	28	18	40	14	20	18	40
Ensis directus	Mollusca	14	21	1	3	4	Mud, Sand	12	0	26	7	32	15	28	15	32
Eriocheir sinensis	Crustacea	30	60	0.5	3	7	All	10	0	25	0	30	12	35	15	32
Ficopomatus enigmaticus	Annelida	20	25	1	7	9	hard	10	0	30	5	40	18	26	10	30
Hemigrapsus sanguineus	Crustacea	16	55	1	5	9	Sand, Hard	40	5	30	15	33	15	30	20	35
Hemigrapsus takanoi	Crustacea	30	30	1	5	9	All	20	0	20	7	35	15	30	25	35
Hydroides dianthus	Annelida	5	14	2	6	10	Hard	200	5	30	28	50	?	20	25	50
Laonome calida	Annelida	1	1.5	1*	7*	8*	All	40*	0	30	0.1	35	?	25	0.1	35
Marenzelleria viridis	Annelida	28	49	1	9	11	Mud	65	0	25	1	32	15	25	5	30
Mytilopsis leucophaeata	Mollusca	6	14	1	5	10	Hard	40	5	37	0	20	13	27	1	25
Mytilus galloprovincialis	Mollusca	14	28	1	6	9	Sand, Hard	40	0	31	12	38	15	25	10	38
Palaemon macrodactylus	Crustacea	15	20	6	4	10	All	40	2	26	1	36	15	27	1	34
Potamocorbula amurensis	Mollusca	14	21	2	5	10	All	30	0	30	0.1	32	6.4	23	0.1	27.6
Rangia cuneata	Mollusca	7	7	0.5	5	10	Mud, Sand	15	1	29	1	15	8	30	2	20
Rapana venosa	Mollusca	14	80	1	4	11	All	40	4	27	7	32	13	26	15	30
Rhithropanopeus harrisii	Crustacea	7	43	1	6	9	Hard	37	0	35	5	30	14	27	5	30

2.3 Larval dispersal modelling

In the following, the methodology applied for larval dispersal modelling is described in a condensed form. A detailed description of the methodology applied for larval dispersal modelling is found in appendix 2 including relevant references, elaborations on the applied assumptions and reservations to be considered.

2.3.1 Hydrographic data

Data on ocean current speed and direction, water temperature and salinity were extracted from a hydrographic dataset generated by the HBM model for the North Sea, Skagerrak, Kattegat, Inner Danish Straits and the Baltic Sea (for details: Berg and Poulsen 2012) with a spatial resolution of 3 nm in the North Sea and Skagerrak and 0.5 nm in the remaining areas. The vertical resolution is 50 and 52 layers respectively. Based on inter annual variations in the North Atlantic Oscillation index (NAO index) the three years 2005, 2010 and 2012 were selected representing “neutral”, “negative” and “positive” NAO indices respectively to reflect expected hydrographic variations between years.

2.3.2 Agent based model

The simulation engine of the SRAAM tool consists of an agent-based modelling library (IBMlib) which is a freeware developed by DTU Aqua (Christensen 2008, Christensen et al., in review). The IBMlib implementation in the SRAAM tool supports a number of larval behaviors and parameters important for predicting larval dispersal. The larval behavior parameters and inputs used in the larval dispersal modelling for the SRA Case study include:

- Pelagic larval duration (PLD)
- Dispersal depth interval
- Spawning start and end
- Spawning and settling habitat
- Vertical dispersion
- Horizontal dispersion

During the larval dispersal simulation IBMlib keeps track of start and end positions of each simulated larvae and minimum and maximum values of salinity and temperature experienced during the pelagic stage. These are used as input to connectivity analysis to construct connectivity matrices and to account for environmental tolerances, see later.

2.3.3 Parameter settings

The pelagic larval duration (PLD) represents the duration of the life stage (typically a larval stage) where the species are freely suspended in the water column and hence subject to passive drift by ocean currents. At the end of the PLD the life stage settle on the sea bed. The PLD values used in the current study were the minimum values of the PLD ranges reported for each species. Data on spawning start and end time are typically described as start and end month of the year and with a reference to specific locations. We use these start and end months as input to the larvae dispersal simulations interpreting the start month as the first day of the month and the end month as the last day of that month. Dispersal depth during the PLD was set to between 0 – 40 meter to comply with general patterns in vertical distribution of pelagic larvae observed by Corell et al. (2012) in the Baltic Sea. The majority of the study area consists of more shallow areas (< 40 m) and the depth distribution here is limited by the water depth. To ensure a random distribution across this depth interval we applied a constant vertical dispersion of 0.001 m^2/s. Horizontal dispersion is included primary to reflect the unresolved hydrodynamics of the hydrographic data at scales smaller than the spatial resolution of the model. The horizontal dispersion was set to 10 m^2/s.

2.3.4 Habitat

Habitat maps for each species were created based on information on species specific preference of seabed substrate, depth distribution and adult life-stages salinity tolerances (Table 1). Seabed substrate distribution was derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (http://www.emodnet-seabedhabitats.eu/), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE). EMODNET substrate data classification was regrouped into 3 main categories "Mud", "Sand" and "Hard substrate", Table 2. In both the "hard" substrate and "Sand" categories we included "Mixed Sediments" and "Coarse Sediments" to reflect transition between the two habitat types. Data on water depth was based on GEBCO bathymetry data set (IOC, IHO and BODC 2003). Data on salinity was based on the hydrographic data from the HBM model by extracting minimum and maximum values of bottom salinity for each year 2005, 2010 and 2012, and by interpolation between extraction points.

Table 2. EMODNET seabed substrate data classified into 3 main categories "Mud", "Sand" and "Hard substrate". Notice that "hard" substrate and "Sand" both include "Mixed Sediments" and "Coarse Sediment".

Mud	Sand	Hard
Fine mud	Sand	Rock or Other hard substrata
Mud to muddy sand	Coarse Sediment	Coarse Sediment
Sandy mud to Muddy sand	Mixed Sediment	Mixed sediments
Muddy Sand		
Sandy Mud		

2.3.5 Simulation setup

The spatial extend of the larval dispersal simulations for each species were setup for a gross area extending 8°-14° E, and 54°–60° N (Figure 3), to include not only the study area of Kattegat and Øresund, but also including the adjacent areas considered to affect population connectivity outputs. The adjacent areas include the Skagerrak, the Inner Danish Straits and the western part of the Baltic. The setup for each species and for each year included 200 000 agents (in total 600 000 agents for all three years) distributed randomly in space within the areal coverage of the species habitat map, and uniform randomly in time within the spawning period. We used a time step of 1800 seconds. Sensitivity analyses were run to test the effects of the number of agents and the dispersal depth on connectivity analysis results.

2.4 Connectivity analysis

All data analyses were carried out using the statistical and data analysis software R (R Core team 2013) using scripts and procedures developed for SRAAM tool (see Hansen et al. 2018). The connectivity analyses were based on a sub-division of the extended area (Figure 3) into a regular grid of 20 x 20 corresponding to a spatial resolution of 0.3 degree in both the latitudinal and longitudinal direction, in the following referred to as the connectivity grid. Connectivity adjacency matrices were constructed from the larval dispersal modelling results comprising start and end positons of each agent, and counting the number of all pairwise connections between sub-areas in the connectivity grid. Only agents with end positions within the species specific habitat were included. Agents exposed to salinity levels outside the larval salinity tolerance were not included.

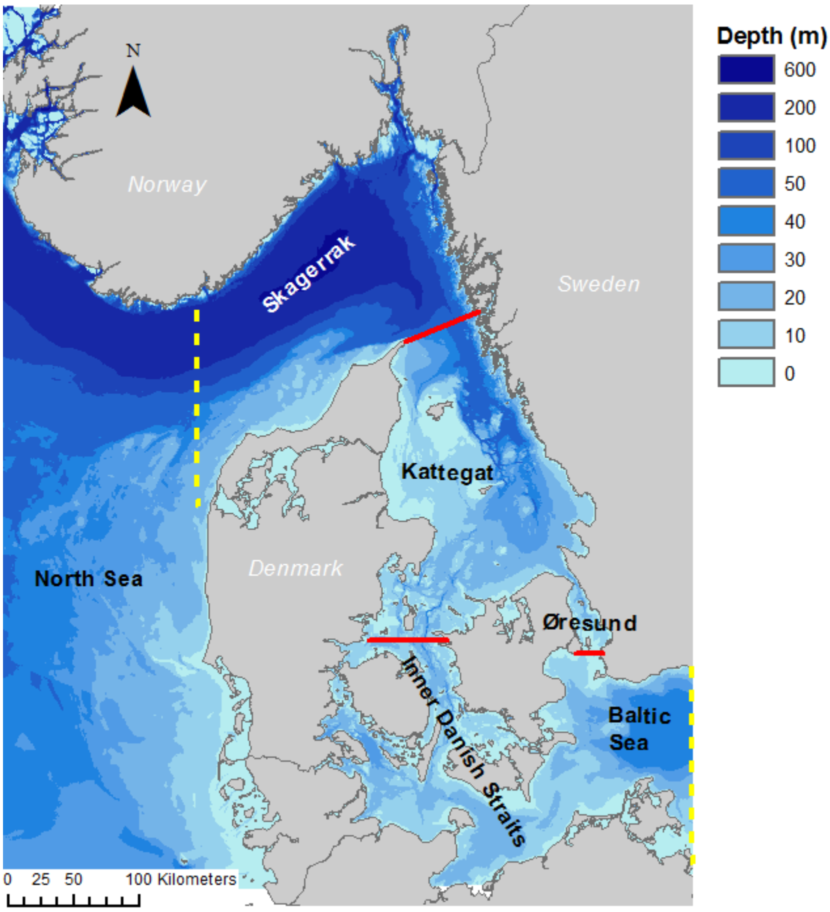


Figure 3. The transition zone between the North Sea and the western Baltic Sea including Skagerrak, Kattegat, Øresund and the Inner Danish Straits. Red lines indicate the outer boundary of the Kattegat and Øresund region. Yellow dotted line indicate the extended area for which the larval dispersal model was setup. Blue color legend show depth interval based on the GEBCO bathymetry dataset.

The connectivity adjacency matrices and the derived connectivity probability matrices were prepared for each species and for each year to identify any differences in connectivity patterns between years, and finally lumped into one matrix for each species representing all years. Hydrographic regions were delineated using cluster analysis each cluster representing assemblies of sub-areas (grid-cells in the 20x20 connectivity grid) where the connectivity between sub-areas within the clusters is high, and where the connectivity to neighboring clusters is low. Here we use the clustering method “Infomap” (Rosvall and Bergstrom 2008) available in the R package “igraph”. The Infomap method is based on information theory principles and has been used recently to delineate hydrographic regions in the Mediterranean (Vincent et al. 2014).

The strength of the connectivity within each identified hydrographic region (referred to as *within regions connectivity*) were calculated as the percentage of the number of agents with an initial position within the region that ends up in the same region. Similarly, the *between regions connectivity's* were calculated as the percentage of the number of agents with an initial position within the region that ends up in each of the neighboring regions. An example of a plot showing within and between regions connectivity is shown in Figure 4.

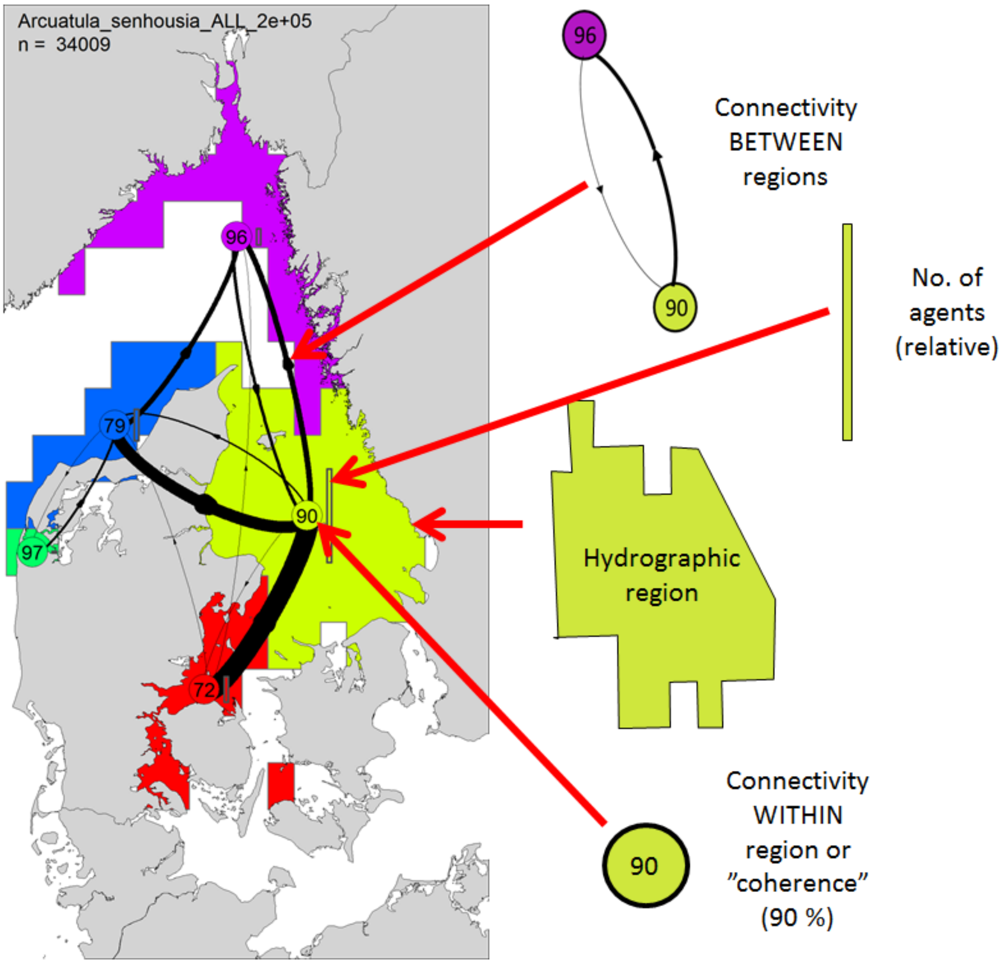


Figure 4. Example of a graph plot representing the outline of hydrographic regions (individual colored polygons) identified for the species *Arcuatula senhousia* based on larval dispersal simulation results for ALL three years (2005, 2010 and 2012) using an initial number of 200 000 agents per year, i.e. a total of 600 000 agents. The number of agents included in the connectivity analysis is 34 009 (n). The number of agents supporting the delineation of each individual region relative to the region with the largest number of agents is represented by bars. The WITHIN region connectivity for each region is represented by node values (circles) representing the percentage of agents with an initial position in each region that end up in the same region. The BETWEEN regions connectivities are indicated by arrows representing the direction of the connectivities and arrow thicknesses representing the relative magnitude of the connectivity (max thickness set to 17% after which it remains unchanged). White areas represent areas outside the larval dispersal extend due to lack of suitable habitat and/or due to unfavorable salinity conditions exceeding the larval salinity tolerance limit. Grey areas are land masses.

All hydrographic regions delineations were calculated based on an assumption of multiple generation stepping stone dispersal using the estimated number of generations within a 5 year period for each species and a between generation survival of 10% . For more details on how to interpret the graph plots, the assumptions applied and additional important considerations please refer to appendix 2. Hydrographic regions for each species delineated based on larval dispersal modelling results lumped for all three years are presented in appendix 2. Hydrographic regions delineated for each species for each year are presented in appendix 3.

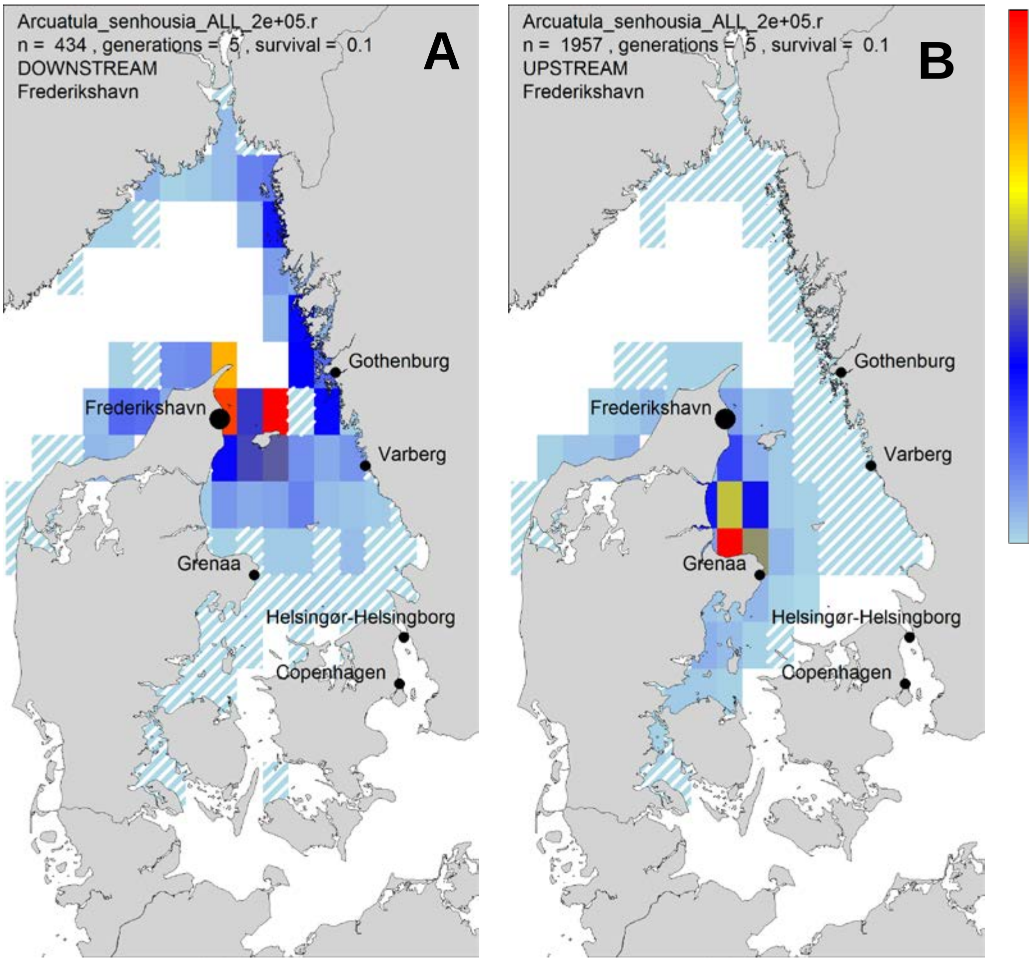


Figure 5. Examples of downstream (A) and upstream (B) dispersal probability maps based on multiple generations dispersal (5 generations and 10 % survival between generations) for the harbor of Frederikshavn. Only agents successfully settled inside species habitats are included. Agents exposed to salinity levels outside the larval salinity tolerance thresholds are not included. Color legend is linear and relative to the largest probability value in each plot. Hatched light blue colors indicate dispersal probability less than 0.1 %. White areas are areas with dispersal probability of "0". Number of agents (n) included in the downstream and upstream probability plot is 434 and 1957 respectively.

To supplement the interpretation of the connectivity from delineated hydrographic regions, Figure 4, a number of maps for each species has been produced visualizing the upstream and downstream dispersal probabilities for 7 major harbors of Kattegat and Øresund including Frederikshavn, Gothenburg, Grenaa, Varberg, Copenhagen, Helsingør and Helsingborg (Figure 5). The latter two are considered as one location. Dispersal probability maps were calculated for both single generation dispersal and for multiple generation dispersal based on estimated number of agents within a 5 year period and a between generation survival of 10 %. Upstream and downstream dispersal probability maps for each species and for each major harbor are presented in appendix 3.

2.5 Interpretation of results

The connectivity analysis is a theoretical and non-validated approach provided to give an estimate on the potential dispersal and connectivity in an area where species has not yet been introduced or where introduction may have occurred but with none or limited population consolidation locally. This potential is by no means synonymously with a risk assessment. Assumptions have to be considered carefully and the translation of each species specific dispersal probabilities and hydrographic region delineations into a risk assessment estimate must be performed in concert with best available knowledge on species life history, invasion history, dispersal potential, and expert judgement and experience. In appendix 2 we describe a number of assumptions and issues that need to be considered before evaluating the risk, some of which are conservative others more non-conservative or liberal. With these assumptions and their implications for result interpretation in mind, connectivity analysis results for each species were evaluated one at the time. Details on the how these issues where considered is outlined in appendix 2. The following parameters were considered:

- **The dispersal potential** of the species expected in the Kattegat and Øresund region
- **The habitat maps** and how well habitats are expected to represent species habitat preferences
- **The robustness** of the larval dispersal simulation and the connectivity analysis results.

The results from the connectivity analysis interpretation for each species is summarized in a table using a simple 3 level scoring principle (Table 3) and considering the connectivity of the whole of Kattegat and Øresund and of five sub-divisions including southern, northern, eastern and western parts of Kattegat and the Øresund itself (Figure 6).

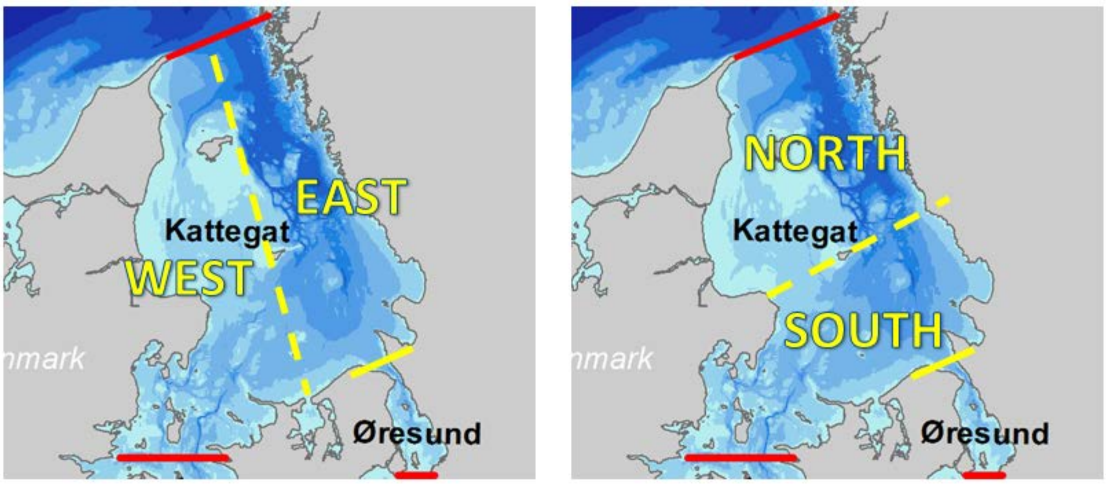


Figure 6. The division of the Kattegat and the Øresund region (within red borders) into 5 subareas used for evaluating and interpretation of connectivity analysis results for each species: North, south, west and east Kattegat and the Øresund. The subdivision is only approximate.

While this subdivision should only be considered as approximate, it was chosen to provide a simplified overview of the connectivity analyses results and to identify which parts of Kattegat and Øresund where connectivity between Danish and Swedish marine areas and harbors may be critical. The ratings for connectivity within Kattegat and Øresund as a whole and within each of the five subdivisions were given rating colors “green”, “yellow”, and “red” (see Table 3):

- Green = high connectivity
- Yellow = low connectivity
- Red = no connectivity.

No color and the text “not included” is used if the area is outside the expected larval dispersal range due to intolerance to experienced simulated salinities, due to the lack of suitable habitat, or in cases where habitat is present then due to the lack of agents successfully settling within suitable habitat. The connectivity of the Kattegat and Øresund as a whole cannot be assigned a connectivity rating better than any of the individual sub-areas, i.e. if connectivity of southern Kattegat is “red”, the connectivity of the whole Kattegat and Øresund will also be assigned the color “red”.

Table 3. Connectivity ratings (“no”, “low” and “high” connectivity) evaluated for each species for the whole of Kattegat and Øresund (KØ) and for each sub-area (Figure 4) representing the North (N), South (S), East (E) and West (W) of Kattegat, and the Øresund (Ø). Additional ratings for the Kattegat and Øresund region as a whole include the “dispersal potential” of the species expected specifically for the region, the ”habitat conditions” in terms for habitat representativeness of habitat map applied in the analysis and the “robustness” of the connectivity results. These are rated “high” (3), “medium”(2) and “low” (1). The presence status of the species in Kattegat and Øresund is also included dividing the species into “not registered” (-), “registered” (+) and “widely distributed” (++).

"...Species name..."						
Dispersal potential	1,2,3					
Habitat conditions	1,2,3					
Pressence status	- / + / ++					
Robustness	1,2,3					
Connectivity:	KØ	N	S	W	E	Ø

(red) = No	1 = Low	-	= Not registered
(yellow) = Low	2 = Medimum	+	= Registered
(green) = high	3 = High	++	= Widely distributed

In addition to the connectivity ratings, Table 3 include ratings on “dispersal potential” of the species expected specifically for the region, the ”habitat conditions” in terms for habitat representativeness of habitat map applied in the analysis and the “robustness” of the connectivity results. These are rated “high” (3), “medium”(2) and “low” (1). The presence status of the species in Kattegat and Øresund is also included dividing the species into “not registered” (-), “registered” (+) and “widely distributed” (++).

2.6 Same-Risk assessment

The premise for an SRA to be assigned is that “same-risk” within an area can be justified. “Same-Risk” is here interpreted as the risk of dispersal of MIS within an area that remains the same or imposes a limited additional but “acceptable risk” if the ballast water is not treated. “Same-Risk” is justified if:

1. The potential natural dispersal of the MIS is interpreted as high

2. The potential natural dispersal of the MIS is low, but…:
    a. The species is already distributed in Kattegat and Øresund
    b. The species has been registered many years ago and still not distributed
    c. Hull fouling is the primary vector relative to ballast water

These criteria can be challenged and will depend on the Danish and Swedish authorities and their interpretation of a “same-risk” or an “acceptable risk”.

Species that do not fulfill the criteria described above will be identified as species that “may pose an additional risk” if an SRA is to be assigned in the Kattegat and Øresund region, and thus potentially limit the extent of an SRA to an area smaller than the Kattegat and Øresund region as a whole.

Because “same-risk” and “acceptable risk” is not objectively defined but depends on the agreements between responsible national authorities, an exact outline of an SRA will depend on the interpretation of to what extent species that may pose a risk (from a connectivity and natural dispersal point of view) may limit the outline of an SRA.

Here we apply a species specific approach and propose two alternatives based on different interpretations on how each species considered may affect an outline of an SRA. In this SRA assessment we discriminate between a “strict” and an “inclusive” interpretation, inspired by Magris et al. (2016), who used the terms in a slightly different context studying the multispecies connectivity of 4 coral reef species but with a comparable objective, namely to be able to depict the range to which connectivity analysis can be interpreted.

- A “STRICT” interpretation here refers to arguments that support the MOST limited SRA delineation.
- An “INCLUSIVE” interpretation her refers to arguments that support the LEAST limited SRA delineation

Arguments will be presented and discussed for each of the two alternatives for each species including species specific information if available including:

- Invasion/introduction history in Kattegat and Øresund and other places
- Natural dispersal potential
- Environmental tolerances (salinity and temperature)
- Habitat conditions and distribution expected in Kattegat and Øresund
- Importance of ballast water as a vector
- Impact potential
- HELCOM/OSPAR target species list
- Uncertainties in larval dispersal modelling and connectivity analysis

3 Same-Risk-Area assessment

3.1 Connectivity results

A summary of the ratings from interpretation of connectivity analysis results presented in appendix 2 is shown in Table 4 along with information on the species dispersal potential, representativeness of the habitat mapping applied in the connectivity analyses and the presence status in the Kattegat and Øresund region. Included in the table is also information on expected impact levels and type, and if the species is known to disperse via hull fouling. Information has been collected from available data portals such as CABI, NOBANIS, NEMISIS, DAISIE, AQUANIS etc. or directly from scientific publications and reports. A column indicates if the species also appear on the HELCOM/OSPAR target list of marine invasive species.

Of the 23 species included in the study, 14 species have been identified as potentially having a high connectivity in the entire Kattegat and Øresund region, or at least in the those parts of the Kattegat and Øresund where larval dispersal is considered possible due to the existing salinity conditions and predicted habitat distribution (Connectivity ratings colored green or white for Kattegat and Øresund in Table 4). These species are considered not to limit the extent of an SRA in Kattegat and Øresund.

Of the remaining 9 species, 3 species have been identified as having a low or uncertain connectivity in at least parts of the Kattegat and Øresund Region. These include:

- *Ensis directus* (Mollusca)
- *Potamocorbula amurensis* (Mollusca)
- *Rhithropanopeus harrisii* (Crustacea)

Finally, the last 6 species have been identified as having no connectivity in the Kattegat and Øresund as a whole or at least parts of Kattegat and Øresund. These include:

- *Bugula neritina* (Bryozoa)
- *Bugulina simplex* (Bryozoa)
- *Didemnum vexilum* (Tunicata)
- *Laonome calida* (Annelida)
- *Mytilopsis leucophaeata* (Mollusca)
- *Rangia cuneate* (Mollusca)

Details on the connectivity analysis results and the interpretation and justification for the final connectivity ratings are thoroughly described for each species in appendices 2 and 3. Species identified to have low or no connectivity in Kattegat and Øresund or parts hereof will be further evaluated in the SRA assessment in the next section.

Table 4. The table incudes a summary of connectivity ratings of the Kattegat and Øresund area, and of the 5 subdivisions hereof including “Western”, “Northern”, “Eastern” and “Southern” Kattegat, and the Øresund (see Figure 6). Connectivity within each (sub-) area is rated in three categories “green”, “yellow” and “red” representing “High”, “Low” and “No” connectivity respectively. The connectivity ratings are supported by a rating of the robustness of the larval dispersal simulation and connectivity analysis. For details on evaluation procedure and connectivity rating justification, see appendix 2. Additional information includes the species dispersal potential, habitat representativeness in the larval dispersal model, the presence status of the species in Kattegat and Øresund, information on hull fouling as an additional transport vector, the expected impact level and type reported for the species, and if the species appear on the HELCOM/OSPAR target list. Translations of the rating values and symbols are shown below the table.

				Connectivity							Same-Risk assessment parameters			
SPECIES	Dispersal potential	Habitat conditions	Pressence status	Robustness	Kattegat & Øresund	Northern Kattegat	Southern Kattegat	Western Kattegat	Eastern Kattegat	Øresund	Helcom/Ospar Target species	attaches to hull	Impact potential	Impact type
Arcuatula senhousia	3	3	-	3	KØ	N	S	W	E	Ø	yes	+	2	ecosystem, biodiversity
Asterias amurensis	3	3	-	3	KØ	N	S	W	E	Ø	yes	+	3	ecosystem, biodiversity
Austrominius modestus	1	1	1	3	KØ	N	S	W	E	Ø	no	++	2	ecosystem, biodiversity, infrastr.
Bugula neritina	1	2	-	3	KØ	N	S	W	E	Ø	no	++	1	fouling
Bugulina simplex	1	1	-	3	KØ	N	S	W	E	Ø	no	+	1	
Callinectes sapidus	2	3	+	3	KØ	N	S	W	E	Ø	yes	-	1	
Crassostrea gigas	3	2	++	3	KØ	N	S	W	E	Ø	yes	+	2	ecosystem, biodiversity
Didemnum vexillum	1	2	-	3	KØ	N	S	W	E	Ø	yes	++	3	ecosystem, biodiversity
Ensis directus	3	3	++	2	KØ	N	S	W	E	Ø	yes	-	1	
Eriocheir sinensis	2	3	+	3	KØ	N	S	W	E	Ø	no	+	2	ecosystem, biodiversity
Ficopomatus enigmaticus	2	2	+	2	KØ	N	S	W	E	Ø	yes	+	2	ecosystem, biodiversity, fouling
Hemigrapsus sanguineus	2	3	+	3	KØ	N	S	W	E	Ø	yes	+	2	ecosystem, biodiversity
Hemigrapsus takanoi	1	2	+	1	KØ	N	S	W	E	Ø	yes	+	2	ecosystem, biodiversity
Hydroides dianthus	2	2	-	3	KØ	N	S	W	E	Ø	yes	++	2	fouling
Laonome calida	2	1	-	3	KØ	N	S	W	E	Ø	no	?	?	
Marenzelleria viridis	3	3	++	3	KØ	N	S	W	E	Ø	yes	-	3	ecosystem, biodiversity
Mytilopsis leucophaeata	2	2	-	3	KØ	N	S	W	E	Ø	yes	+	3	fouling
Mytilus galloprovincialis	3	3	-	3	KØ	N	S	W	E	Ø	yes	+	2	biodiversity
Palaemon macrodactylus	3	3	-	3	KØ	N	S	W	E	Ø	yes	+	1	
Potamocorbula amurensis	3	3	-	3	KØ	N	S	W	E	Ø	yes	-	3	ecosystem, biodiversity
Rangia cuneata	1	1	-	3	KØ	N	S	W	E	Ø	yes	?	3	ecosystem, biodiversity, fouling
Rapana venosa	3	3	-	3	KØ	N	S	W	E	Ø	yes	?	3	ecosystem, biodiversity, fouling
Rhithropanopeus harrisii	2	2	+	3	KØ	N	S	W	E	Ø	yes	+	2	fouling, fishing gear

Dispersal potential	1 (low), 2 (medium), 3 (high)
Habitat conditions	1 (low), 2 (medium), 3 (high)
Pressence Kattegat Øresund	Not registered (-), Registered (+), widely distributed (++), registreation uncertain (?)
Robustness (of results)	1 (low), 2 (medium), 3 (high)
Connectivity:	= No = Low = high = Outside larval salinity tolerance or suitable habitat
Hull attachments	No (-), Registered vector (+), Dominant vector (++)
Impact	1 (low), 2 (medium), 3 (high)

3.2 Same-Risk rating

Of the 9 species identified as having low or no connectivity in the whole of Kattegat and Øresund or at least parts hereof (Table 5), 3 species have been rated as not posing an additional risk in case of an assignment of an SRA to the Kattegat and Øresund region despite low natural dispersal and connectivity. These include 2 species, *Bugulina neritina* and *Didemnum vexillum*, which are considered to be associated with hull fouling as the primary vector of transport with ships relative to transport via ballast water. Both species have been described as having low or no impact and *B. neritina* is not on the HELCOM/OSPAR target species list. The third species *Ensis directus* is considered to be widely distributed in the Kattegat and Øresund for decades but in low abundances and with no invasive behavior reported.

Table 5. Same-Risk assessment for the 9 identified species where connectivity may be limited in the whole, or parts, of Kattegat and Øresund. The Same-Risk assessment has been evaluated based two criteria (right most column). 1 (Green) = Same Risk may be justified in the whole of Kattegat and Øresund. 2 (yellow) = Same Risk may be limited to parts of Kattegat and Øresund. Translations of the rating values and symbols other than the "Same Risk rating" column, see Table 4.

SPECIES	Dispersal potential	Habitat conditions	Pressence status	Connectivity							Same-Risk assessment			Same Risk rating
				Robustness	Kattegat & Øresund	Northern Kattegat	Southern Kattegat	Western Kattegat	Eastern Kattegat	Øresund	Helcom/Ospar Target species	Attaches to hull	Impact potential	
Bugula neritina	1	2	-	3	KØ	N	S	W	E	Ø	no	++	1	
Bugulina simplex	1	1	-	3	KØ	N	S	W	E	Ø	no	+	1	
Didemnum vexillum	1	2	-	3	KØ	N	S	W	E	Ø	yes	++	3	
Ensis directus	3	3	++	2	KØ	N	S	W	E	Ø	yes	-	1	
Laonome calida	2	1	-	3	KØ	N	S	W	E	Ø	no	?	?	
Mytilopsis leucophaeata	2	2	-	3	KØ	N	S	W	E	Ø	yes	+	3	
Potamocorbula amurensis	3	3	-	3	KØ	N	S	W	E	Ø	yes	-	3	
Rangia cuneata	1	1	-	3	KØ	N	S	W	E	Ø	yes	?	3	
Rhithropanopeus harrisii	2	2	+	3	KØ	N	S	W	E	Ø	yes	+	2	

Same-Risk rating

Same Risk may be justified in the whole of Kattegat and Øresund

Same Risk may be limited to parts of Kattegat and Øresund

For the remaining 6 species, ballast water is considered to be an important vector for ship-mediated transport of MIS and these species are considered potentially limiting the extent of an SRA.

3.3 SRA delineation alternatives

SRA delineation alternatives considering a strict and inclusive interpretation are presented for the 6 species identified as potentially being limiting the extent of an SRA.

3.3.1 SRA limited by *Bugulina simplex*

The SRA delineation alternatives for *Bugulina simplex* are shown in Figure 7 together with delineated hydrographic regions and predicted habitat map.

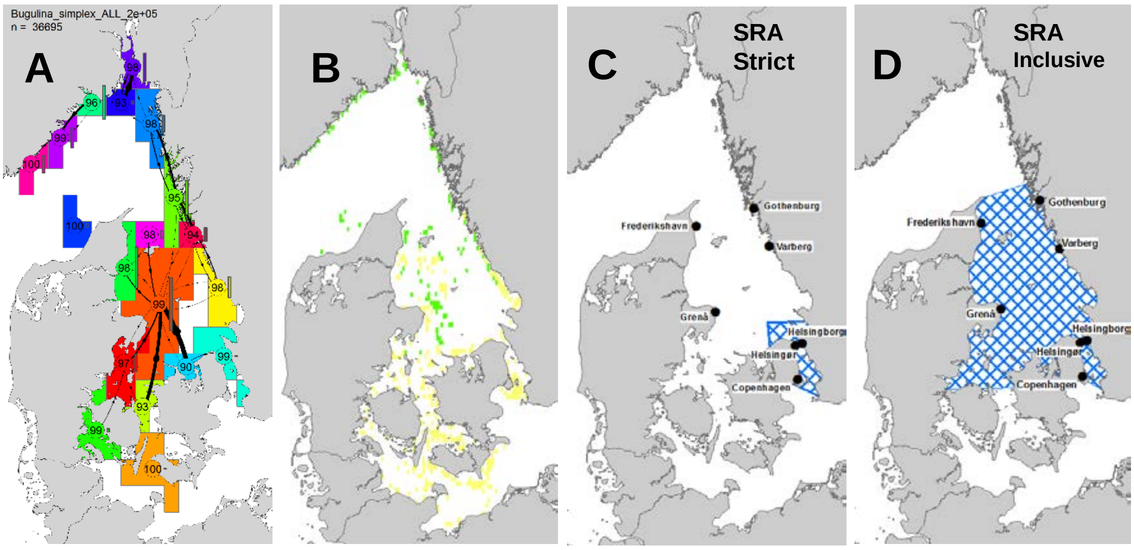


Figure 7. SRA assessment for *Bugulina simplex*: **A: Hydrographic regions including within and between regions connectivities (for details see appendix 2). B: Habitat map discriminating between "optimal" (green) and "sub-optimal" (yellow) salinity conditions for adult life stages. The SRA delineated alternatives for Kattegat and Øresund based on a strict (C) and an inclusive (D) interpretation are represented by blue colored patterns.**

Strict interpretation

- The species connectivity is highly limited with only natural dispersal occurring in Øresund. The rest of Kattegat is considered not to be connected via natural dispersal.

Inclusive interpretation

- Most of Kattegat and Øresund except for northern Kattegat and deeper parts of central Kattegat are located in sub-optimal salinity conditions for adult life stages.
- The species is regarded as having a low impact.
- Hull fouling is believed to be an equally important vector relative to ballast water.
- The species is not included in the HELCOM/OSPAR target species list.
- The species is not registered in the Kattegat and Øresund region.

SRA alternatives

Arguments considering a strict interpretation support an SRA restricted to the Øresund. Arguments considering an inclusive interpretation may support an SRA assigned to the whole of Kattegat and Øresund.

3.3.2 SRA limited by *Laonome calida*

The SRA delineation alternatives for *Laonome calida* are shown in Figure 8 together with delineated hydrographic regions and predicted habitat map.

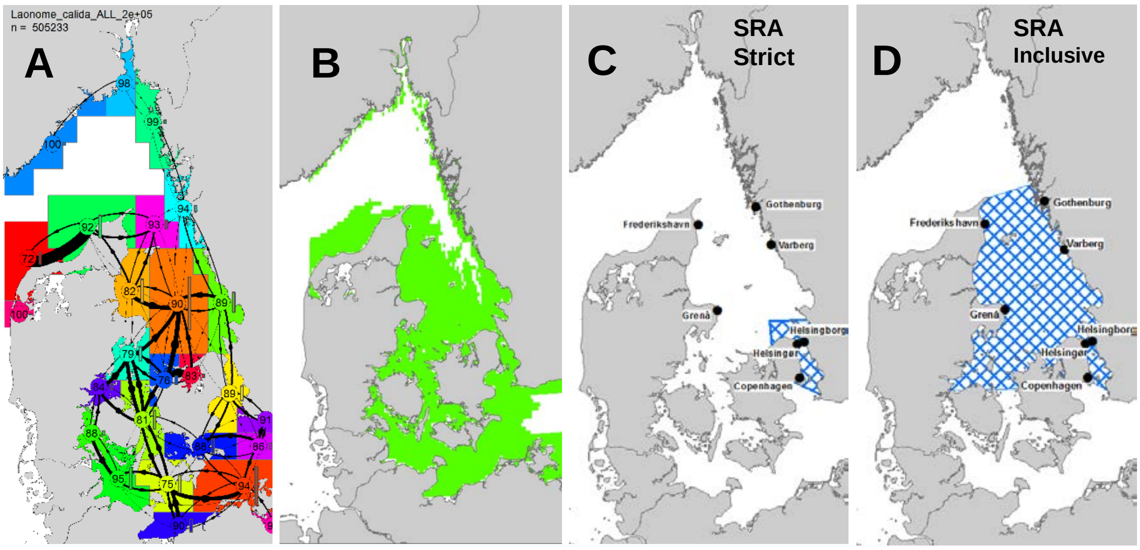


Figure 8. SRA assessment for *Laonome calida*: **A: Hydrographic regions including within and between regions connectivities (for details see appendix 2). B: Habitat map discriminating between "optimal" (green) and "sub-optimal" (yellow) salinity conditions for adult life stages. The SRA delineated alternatives for Kattegat and Øresund based on a strict (C) and an inclusive (D) interpretation are represented by blue colored patterns.**

Strict interpretation

- The species connectivity is highly limited due to low PLD (1 day)
- The assumed habitat may be overestimated in which case the connectivity will be further limited
- The impact potential of the species is regarded as high.
- The species is assumed to be tolerant to almost the whole salinity range from < 1 to > 30 PSU.
- Very little is known about the species and the therefor the risk is difficult to evaluate.

Inclusive interpretation

- The taxonomy of the species has been questioned and reports may comprise different species.
- Adult salinity tolerance range is uncertain. In Europe the species has been found solely in relation to salinity conditions more brackish than in Kattegat and Øresund.
- Larval salinity tolerance range unknown.
- The species is not yet recorded in Kattegat and Øresund.
- The species is not on the HELCOM/OSPAR target species list.

SRA alternatives

Arguments considering a strict interpretation support an SRA restricted to the Øresund. Arguments considering an inclusive interpretation may support an SRA assigned to the whole of Kattegat and Øresund.

3.3.3 SRA limited by *Mytilopsis leucophaeata*

The SRA delineation alternatives for *Mytilopsis leucophaeta* are shown in Figure 9 together with delineated hydrographic regions and predicted habitat map.

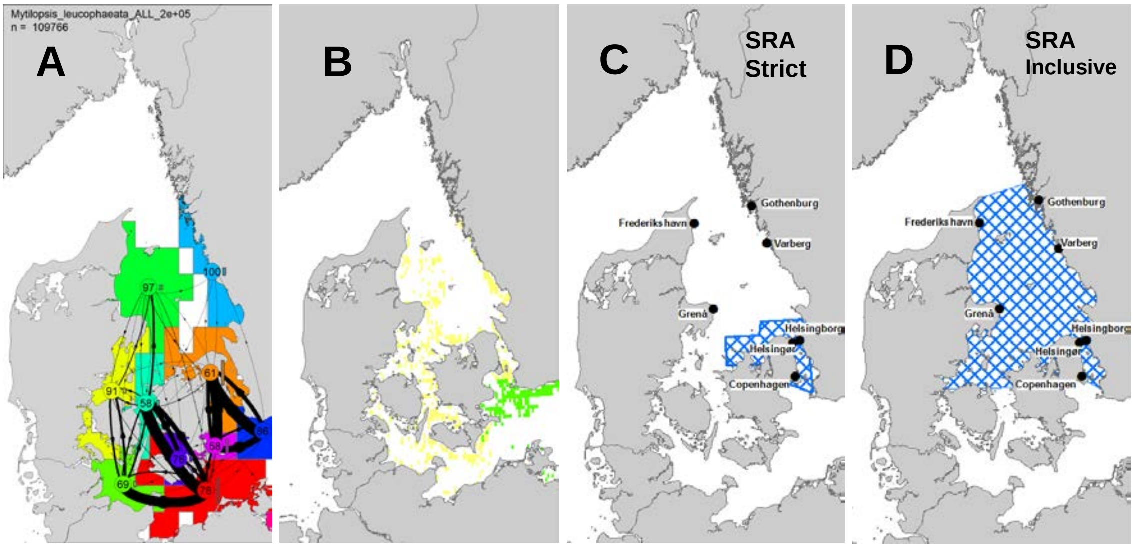


Figure 9. SRA assessment for *Mytilopsis leucophaeata*: **A: Hydrographic regions including within and between regions connectivities (for details see appendix 2). B: Habitat map discriminating between "optimal" (green) and "sub-optimal" (yellow) salinity conditions for adult life stages. The SRA delineated alternatives for Kattegat and Øresund based on a strict (C) and an inclusive (D) interpretation are represented by blue colored patterns.**

Strict interpretation

- The species connectivity in Kattegat is highly limited. Only the Øresund and southeastern corner of Kattegat is well connected.
- The species is on the HELCOM/OSPAR target species list.
- The species recognized as having a high impact potential.

Inclusive interpretation

- The whole of Kattegat is located in sub-optimal salinity conditions for adult life stages and it is uncertain if the species can establish here.
- Limited east-west connectivity is partly due to larval salinity intolerance.
- The calculated connectivity is based on a minimum PLD of 6 days but values up to 14 days has been recorded. Thus, the connectivity may be underestimated.
- The species has been registered in Europe since 1835 in the North Sea and Baltic Sea in relation to freshwater outlets. The lack of being widely distributed in the Kattegat and Øresund region indicates that the species may not impose a risk to an SRA designation.
- Winter temperatures may be a limiting factor the ability of the species to establish.

SRA alternatives

Arguments considering a strict interpretation support an SRA restricted to the Øresund and the most south-eastern corner of the Kattegat. Arguments considering an inclusive interpretation may support an SRA assigned to the whole of Kattegat and Øresund.

3.3.4 SRA limted by *Potamocorbula amurensis*

The SRA delineation alternatives for *Potamocorbula amurensis* are shown in Figure 10Figure 9 together with delineated hydrographic regions and predicted habitat map.

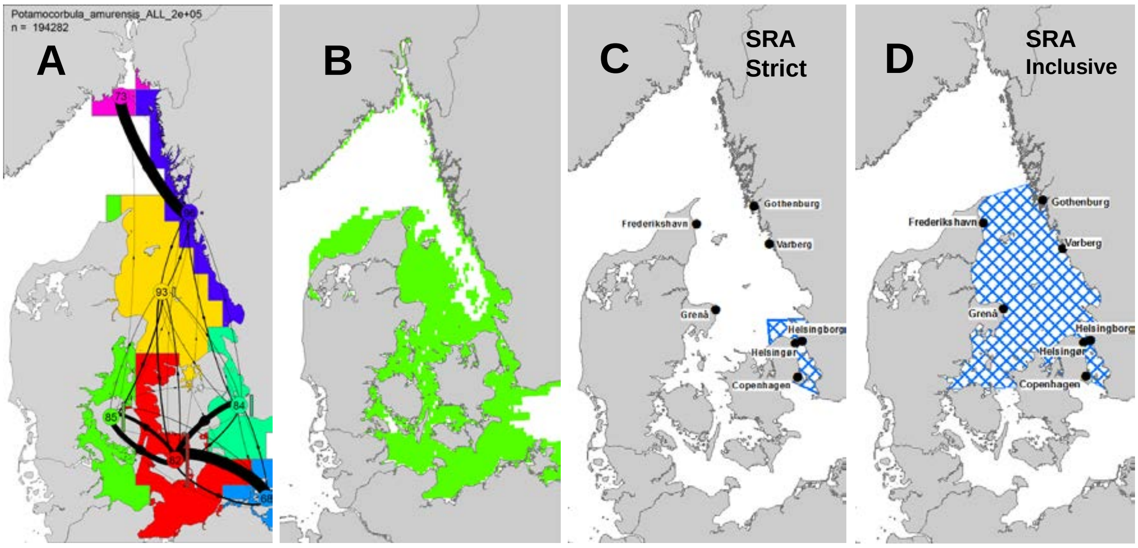


Figure 10. SRA assessment for *Potamocorbula amurensis*: **A: Hydrographic regions including within and between regions connectivities (for details see appendix 2). B: Habitat map discriminating between "optimal" (green) and "sub-optimal" (yellow) salinity conditions for adult life stages. The SRA delineated alternatives for Kattegat and Øresund based on a strict (C) and an inclusive (D) interpretation are represented by blue colored patterns.**

Strict interpretation

- The species connectivity in is limited in the east-west direction in the most eastern parts of Kattegat.
- The species is reported as having a high impact potential.
- The species is on the HELCOM/OSPAR target species list.

Inclusive interpretation

- The limited connectivity from east to west in the eastern parts of Kattegat is partly due to this part of the region being close to the upper salinity tolerance range expected for larval stages
- The species has not been registered in Kattegat and Øresund.
- The PLD range from 14 - 21 days indicates that the connectivity analysis based on 14 days PLD can be somewhat underestimated.
- The species is reported to have a high dispersal potential.

SRA alternatives

Arguments considering a strict interpretation support an SRA restricted to the Øresund. Arguments considering an inclusive interpretation may support an SRA assigned to the whole of Kattegat and Øresund.

3.3.5 SRA limted by *Rangia cuneate*

The SRA delineation alternatives for *Rangia cuneate* are shown in Figure 11 together with delineated hydrographic regions and predicted habitat map.

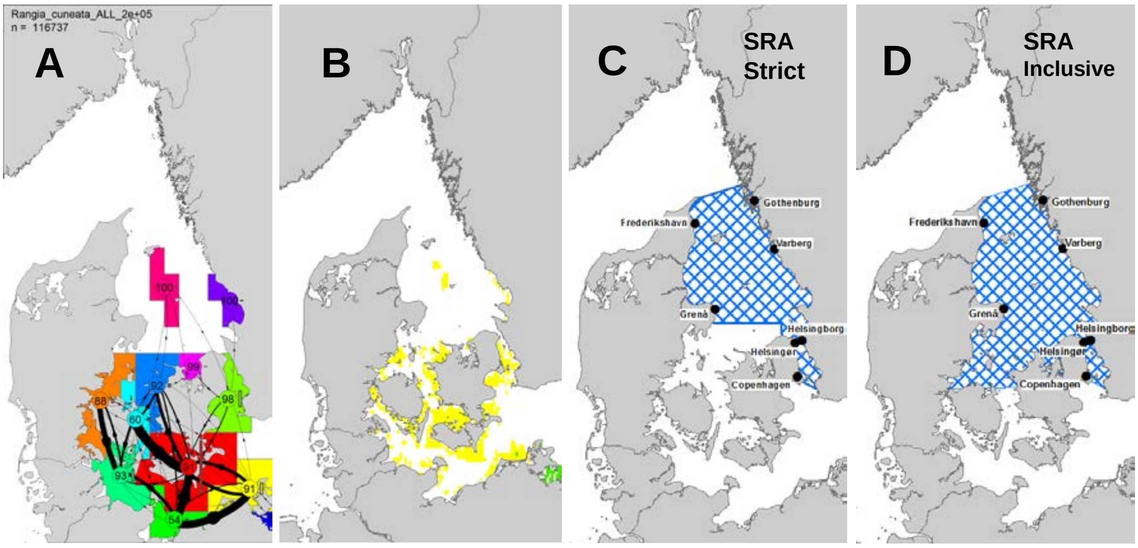


Figure 11. SRA assessment for *Rangia cuneate*: **A: Hydrographic regions including within and between regions connectivities (for details see appendix 2). B: Habitat map discriminating between "optimal" (green) and "sub-optimal" (yellow) salinity conditions for adult life stages. The SRA delineated alternatives for Kattegat and Øresund based on a strict (C) and an inclusive (D) interpretation are represented by blue colored patterns.**

Strict interpretation

- The species connectivity within the larval dispersal range is highly limited due to very short PLD. Only Øresund is considered as well connected.
- The species is reported having a high impact potential.

Inclusive interpretation

- The salinity conditions for adult life stages in whole of Kattegat and Øresund are sub-optimal.
- The larval dispersal range is limited to the southern parts of Kattegat and Øresund. Larval survival in these parts of the region may be uncertain.
- Dispersal potential in general is reported to be moderate
- The species is not registered in the region.

SRA alternatives

Arguments considering a strict interpretation support an SRA restricted to the Øresund and the central and northern parts of Kattegat. Arguments considering an inclusive interpretation may support an SRA assigned to the whole of Kattegat and Øresund.

3.3.6 SRA limited by *Rhithropanopeus harrisii*

The SRA delineation alternatives for *Rhithropanopeus harrisii* are shown in Figure 12 together with delineated hydrographic regions and predicted habitat map.

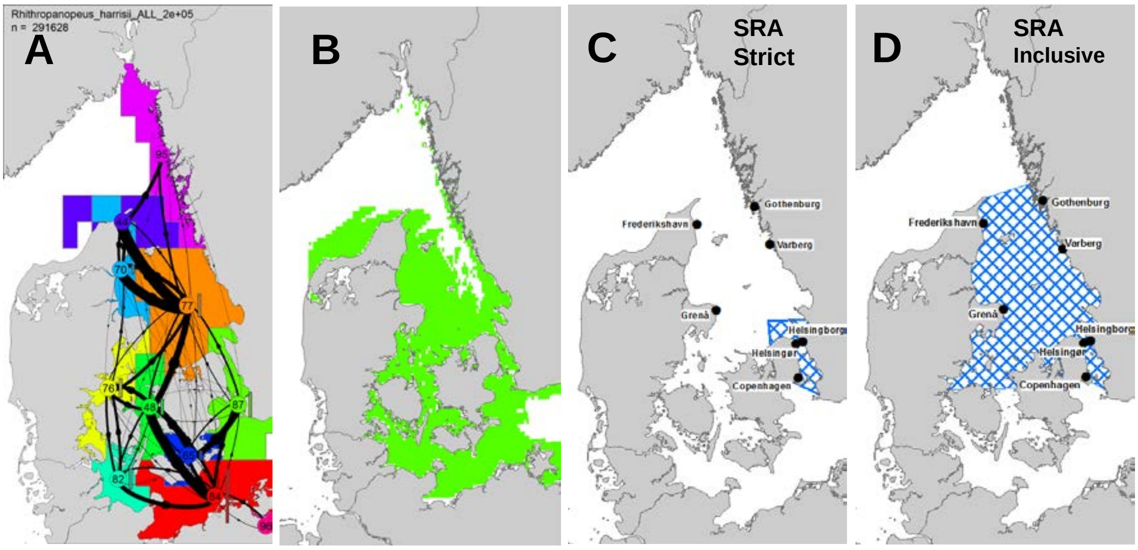


Figure 12. SRA assessment for Rhithropanopeus harrisii: A: Hydrographic regions including within and between regions connectivities (for details see appendix 2). B: Habitat map discriminating between “optimal” (green) and “sub-optimal” (yellow) salinity conditions for adult life stages. The SRA delineated alternatives for Kattegat and Øresund based on a strict (C) and an inclusive (D) interpretation are represented by blue coloured patterns.

Strict interpretation

- The connectivity in the whole of Kattegat is uncertain, while Øresund is interpreted as well connected.
- The habitat assumed in the connectivity analysis may be overestimated further limiting the connectivity.
- The species has recently been established south of Øresund
- The specie is on the HELCOM/OSPAR target species list.

Inclusive interpretation

- The PLD range 7- 43 days indicates that the connectivity analysis based on 7 days PLD can be significantly underestimated and the whole of Kattegat may be well connected.
- The species attach to hull as a contributing vector of transport.
- The species has been recorded in Copenhagen area since 1957 and only recently established locally.
- The dispersal potential in general is reported as moderate.
- The impact potential in general is reported as moderate.

SRA alternatives

Arguments considering a strict interpretation support an SRA restricted to the Øresund. Arguments considering an inclusive interpretation may support an SRA assigned to the whole of Kattegat and Øresund.

4 Discussion and conclusion

In this SRA Case Study for Kattegat and Øresund, we have presented a methodology on how to address a risk assessment as required by the Ballast Water Management Convention before an SRA can be assigned to a marine territory between two or more countries.

The methodology employs connectivity to focus on the predicted natural dispersal of marine invasive species not introduced or introduced but not widely distributed in the region. The predicted natural dispersal is used as a key indicator to identify species potentially posing a risk if ballast water remains untreated and species which may not, i.e. thus supporting an SRA. A long list of +80 species based on internationally agreed invasive species for the North Sea and the Baltic Sea was reduced to 23 based primarily on salinity tolerance. Of the 23, the study identified 9 species that were considered to have a natural dispersal, which would potentially limit an SRA to less than the study area of Kattegat and Øresund.

In further consideration of risk, the 9 species were assessed using additional available knowledge on species characteristics such as species biology, habitat requirements, environmental tolerances, invasion history, the importance of ballast water as a vector, impact potential etc. While 3 species were readily “low risk”, 6 species require an expert assessment and for this we identify and present for each species arguments that support each of two different alternative SRA delineations: One based on accepting only conservative choice of data supporting the most limited SRA delineation (referred to as a “strict” interpretation) and one allowing a consensus based data selection supporting the least limited SRA delineation (referred to as an “inclusive” interpretation).

- By applying a strict interpretation an SRA can be argued to be limited to covering only the Øresund and the immediate vicinity (in 5 out 6 species).
- By applying an inclusive interpretation, it may be argued that the whole of Kattegat and Øresund can be assigned as an SRA (for all 6 species).

None of the 23 species was found to limit the extent of an SRA covering the Øresund. The final decision on what is “an acceptable risk” needs to be addressed by respective authorities in Denmark and Sweden, since this requires that arguments of supporting the strict approach be considered within “an acceptable risk”.

The study did not consider how an SRA may be identified in cases where two or more harbors are permanently affected by freshwater but separated in an otherwise saline environment, e.g. between minor ports in Denmark and Sweden in connections with rivers and the interior parts of long fjords, e.g. Mariager Fjord. In such cases, authorities may consider a conditional SRA excluding specific harbors from the exemption provided by an SRA.

Many of the assumptions, parameters and criteria applied in the methodological approach presented here may of course be challenged. We have not aimed at defining exact quantitative criteria to support the expert risk assessment. Although results from the larval dispersal simulation and connectivity analysis are based on quantitative methods, at best the results can only be regarded as semi-quantitative. Because some factors that may affect larval dispersal are unknown or inaccurate, and since we consider only the larval dispersal phase and not the entire life cycle included in population establishment, maintenance and succession, the analysis can only be indicative. Thus, the final same-risk assessment relies largely on qualitative indices which can be difficult to interpret and evaluate, and will require some kind of consensus and agreement among stakeholders. This part has been beyond the scope of this project. Instead we have developed and presented a transparent methodology that can be reproduced, and where scientific disagreements in the applied criteria, parameters and assumptions can be easily tested to examine how this will affect the results. This is the case in particular for the species selection criteria, the larval dispersal modelling approach and the connectivity analysis. In the final same-risk assessment the scope has been to present necessary information for decision makers by identifying species that may be considered as posing an additional risk to the region if ballast water remains untreated, and to present the range of arguments the decisions makers need to consider when addressing what is an “acceptable risk” and the means to decide on the extent of an eventually SRA assignment.

As suggested by Stuer-Lauridsen et al. (2018) the SRA study presented here is based on a species-specific risk assessment approach also as proposed by the BWMC guideline G7. The G7 proposes three risk assessment methods including “Environmental matching risk assessment”, “Species biogeographical risk assessment” and “Species specific risk assessment”. We argue that the approach presented here also incorporates principles of an “Environmental matching risk assessment”, because we take into account the effect of habitat distribution and environmental tolerances explicitly in the larval dispersal simulation and connectivity analysis, and in the interpretation of results and in the preliminary risk assessment.

5 References

Anglès d'Auriac M B, Rinde E, Norling P, Lapègue S, Staalstrøm A, Hjermann D Ø, Thaulow J, 2017. Rapid expansion of the invasive oyster *Crassostrea gigas* at its northern distribution limit in Europe: Naturally dispersed or introduced? PLoS ONE 12(5): e0177481. https://doi.org/10.1371/journal.pone.0177481

AquaNIS. Editorial Board, 2015. Information system on Aquatic Non-Indigenous and Cryptogenic Species. World Wide Web electronic publication. www.corpi.ku.lt/databases/aquanis. Version 2.36+. Accessed 2018-10-01.

Ashworth J, 2017. Marine Microalgae: Systems Biology from ‘Omics’. In: Kumar M, Ralph P (eds) Systems Biology of Marine Ecosystems. Springer, Cham. https://doi.org/10.1007/978-3-319-62094-7_10

Berg P, Poulsen J W, 2012. Implementation Details for HBM. DMI Technical Report, No. 12-11, Copenhagen.

Bochert R 1997. *Marenzelleria viridis* (Polychaeta: Spionidae): a review of its reproduction. Aquatic Ecology 31: 163–175, 1997.

Brink A v d, Godschalk M, Smaal A C, Lindeboom H J, 2013. Some like it hot: The effect of temperature on brood development in the invasive crab *Hemigrapsus takanoi* (Decapoda: Brachyura: Varunidae). Journal of the Marine Biological Association of the UK 93(1):189-196. DOI: 10.1017/S0025315412000446.

Brooks S J, & Farmen E, 2013. The distribution of the mussel Mytilus species along the Norwegian coast. Journal of Shellfish Research, 32, 265–270.

Cain T D 1973. The combined effects of Temperature and salinity on embryos and larvae of the clam *Rangia cuneata*. Marine Biology 21: 1-6

Capa M, Moorsel G V, Tempelman D, 2014. The Australian feather-duster worm *Laonome calida* Capa, 2007 (Annelida: Sabellidae) introduced into European inland waters? BioInvasions Records (2014) Volume 3, Issue 1: 1–11. doi: http://dx.doi.org/10.3391/bir.2014.3.1.01

Carlton J; Geller J, 1993. Ecological roulette: The global transport of nonindigenous marine organisms. Science, 261:78-82.

Chen D and Hellström, 1999. The influence of the North Atlantic Oscillation on the regional temperature variability in Sweden: spatial and temporal variations. Tellus (1999), 51A, 505–516

Christensen A, 2008, Bank resolved prognoses of sandeel fishing potential in the North Sea”. Final report for the project "Fiskeriudsigt for tobis i Nordsøen på bankeniveau. (FIUF, 2005-2007).

Christensen A, Mariani P, Payne M R, in review. A generic framework for individual-based modelling and physical-biological interaction. Environmental Modelling and Software.

Chung E Y, Kim S Y, Park K H, Park G M, 2002. Sexual maturation, spawning, and deposition of the egg capsules of the female purple shell, *Rapana venosa* (Gastropoda : Muricidae). January 2002. Malacologia

Hurrell, J & National Center for Atmospheric Research Staff (Eds). Last modified 04 Aug 2018. "The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (station-based)." Retrieved from https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based 44(2):241-257

Cooper R B 1981. Salinity tolerance of *Rangia cuneata* (Pelycypoda: Mactridae) in relation to its estuarine environment: a review. Walkerana 1:19 – 31.

Corell H, Moksnes PO, Engqvist A, Döös K, Jonsson PR (2012) Depth distribution of larvae critically affects their dispersal and the efficiency of marine protected areas. Mar Ecol Prog Ser 467:29-46. https://doi.org/10.3354/meps09963

DAISIE European Invasive Alien Species Gateway, 2018. Available from: http://www.europe-aliens.org/speciesFactsheet.do?speciesId=5179 [Accessed November 2018].

Drinkwater, K. F., Belgrano, A., Borja, A., Conversi, A., Edwards, M., Greene, C. H., Ottersen, G., Pershing, A. J. and Walker, H. (2003) The Response of Marine Ecosystems to Climate Variability Associated with the North Atlantic Oscillation, in The North Atlantic Oscillation: Climatic Significance and Environmental Impact (eds J. W. Hurrell, Y. Kushnir, G. Ottersen and M. Visbeck), American Geophysical Union, Washington, D. C.. doi: 10.1029/134GM10

Dolmer P, Holm M W, Strand Å., Lindegarth S, Bodvin T, Norling P, & Mortensen S, 2014. The invasive Pacific oyster, *Crassostrea gigas*, in Scandinavia coastal waters: A risk assessment on the impact in different habitats and climate conditions. Institute of Marine Research. Fisken og Havet. Vol. 2

Fofonoff P W, Ruiz G M, Steves B, Simkanin C, Carlton J T, 2018. National Exotic Marine and Estuarine Species Information System.http://invasions.si.edu/nemesis/. Access Date: 27-Sep - 2018

Gittenberger A, 2007. Recent population expansions of non-native ascidians in The Netherlands. Journal of Experimental Marine Biology and Ecology [Proceedings of the 1st International Invasive Sea Squirt Conference, Woods Hole, Massachusetts, USA, April 21-22, 2005.], 342(1):122-126. http://www.sciencedirect.com/science/journal/00220981

Global Invasive Species Database (2018) Species profile: *Rapana venosa*. Downloaded from http://www.iucngisd.org/gisd/species.php?sc=691 on 28-09-2018.

Goldberg C S, Turner C R, Deiner K, Klymus K E, Thomsen P F, Murphy M A, Spear S F, McKee A, Oyler-McCance S J, Cornman R S, Laramie M B, Mahon A R, Lance R F, Pilliod D S, Strickler K M, Waits L P, Fremier A K, Takahara T, Herder J E, Taberlet P, 2016. REVIEW Critical considerations for the application of environmental DNA methods to detect aquatic species. Methods in Ecology and Evolution, 7, pp. 1299–1307

Hansen F T, Christensen A, 2018. Same-Risk-Area Assessment Model (SRAAM). User's manual. Version 2.0. DTU Aqua report no. 332-2018

HELCOM and OSPAR 2015. Joint Harmonised Procedure for the Contracting Parties of HELCOM and OSPAR on the granting of exemptions under International Convention for the Control and Management of Ships' Ballast Water and Sediments, Regulation A-4. Adopted as OSPAR Agreement 2013-09 and by HELCOM Ministerial Meeting Copenhagen 3 October 2013. Amended by HELCOM HOD 48-2015 (June) and OSPAR Agreement 2015-01.

Hench J L, Forward R B, Carr S D, Rittshof D, Luettich R A, 2004. Testing a selective tidal-stream transport model: Observations of female blue crab (Callinectes sapidus) vertical migration during the spawning season. Limnol. Oceanogr., 49(5), 2004, 1857–1870.
JOURNAL ARTICLE

Hoegh-Guldberg O and Pearse J S, 1995. Temperature, Food Availability, and the Development of Marine Invertebrate Larvae. American Zoologist. Vol. 35, No. 4 (Sep., 1995), pp. 415-425

ICES, 2004. Alien Species Alert: *Rapana venosa* (veined whelk). ICES Cooperative Research Report No. 264 [ed. by Roger Mann, Anna Occhipinti , Juliana Harding M].

IOC, IHO and BODC, 2003, "Centenary Edition of the GEBCO Digital Atlas", published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans; British Oceanographic Data Centre, Liverpool

Jahnke M, Jonsson P R, Moksnes P-O, Loo L-O, Jacobi M N, Olsen J L. 2018. Seascape genetics and biophysical connectivity modelling support conservation of the seagrass *Zostera marina* in the Skagerrak–Kattegat region of the eastern North Sea. Evol Appl. 2018;11:645–661. https://doi.org/10.1111/eva.12589

Jensen K 2013. Selection of target species for risk assessment of danish ports in connection with the international convention for the control and management of ships' ballast water and sediments. Report for the Danish Nature Agency

Jungblut S, Beermann J, Boos K, Saborowski R and Hagen W, 2017. Population development of the invasive crab *Hemigrapsus sanguineus* (De Haan, 1853) and its potential native competitor *Carcinus maenas* (Linnaeus, 1758) at Helgoland (North Sea) between 2009 and 2014. Aquatic Invasions (2017) Volume 12, Issue 1: 85–96.
DOI: https://doi.org/10.3391/ai.2017.12.1.09

Kashenko S D 2002. The Reaction of the Starfish *Asterias amurensis* and *Patiria pectinifera* (Asteroidea) from Vostok Bay (Sea of Japan) to a Salinity Decrease. Russian Journal of Marine Biology, Vol. 29, No. 2, 2003, pp. 110–114.

Kauppi L, Norkko A, Norkko j, 2018. Seasonal population dynamics of the invasive polychaete genus *Marenzelleria* spp. in contrasting soft-sediment habitats. Journal of Sea Research 131 (2018) 46–60.

Keough M J 1989. Dispersal of the bryozoan *Bugula neritina* and effects of adults on newly metamorphosed juveniles. Mar. Ecol. Prog. Ser. Vol. 57, 163- 171.

Klassen G, 2012. A biological synopsis of the Asian shore crab, *Hemigrapsus sanguineus*. Can. Manuscr. Rep. Fish. Aquat. Sci. 2978: v + 43 p.

Kristensen E, Banta G, Quintana C O, Delefosse M, Flindt M R, 2012. Hvad ved vi om den invasive svovlorm, *Marenzelleria viridis*? Vand og Jord. 19. årgang nr. 1, februar 2012, 31

Laine A O, Mattila J and Lehikoinen A, 2006. First record of the brackish water dreissenid bivalve *Mytilopsis leucophaeta* in the northern Baltic Sea. Aquatic Invasions 1: 38-41.

Leone D E 1970. The maturation of *Hydroides dianthus*. The Biological Bulletin 138, no. 3 (june 1970): 306-315.

MEPC 2017. Resolution mepc.289(71) (adopted on 7 July 2017) 2017 guidelines for risk assessment under regulation a-4 of the BWM convention (g7).

Miljøstyrelsen 2017. Faktaark for invasive arter. From www.mst.dk. Accessed 24.09.2018.

MolluscaBase (2018). *Mytilus galloprovincialis* Lamarck, 1819. Accessed through: World Register of Marine Species at: http://www.marinespecies.org/aphia.php?p=taxdetails&id=140481 on 2018-09-27

Möller T,Kotta J, 2017. *Rangia cuneata* (G. B. Sowerby I, 1831) continues its invasion in the Baltic Sea: the first record in Pärnu Bay, Estonia. BioInvasions Records (2017) Volume 6, Issue 2: 167–172. DOI: https://doi.org/10.3391/bir.2017.6.2.13

R Core Team, 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Rome M S, Young-Williams A C, Davis G R, Hines A H, 2005. Linking temperature and salinity tolerance to winter mortality of Chesapeake Bay blue crabs (*Callinectes sapidus*). Journal of Experimental Marine Biology and Ecology. Volume 319, Issues 1–2, 1 June 2005, Pages 129-145. https://doi.org/10.1016/j.jembe.2004.06.014

Roussel J M, Paillisson J M, Treguier A T and Petit E. 2015. The downside of eDNA as a survey tool in water bodies. Journal of Applied Ecology 2015, 52, 823–826

Ryland J S, Bishop J D D, De Blauwe H, Nagar A E, Minchin D, Wood C A, Yunnie A L E, 2011. Alien species of *Bugula (*Bryozoa) along the Atlantic coasts of Europe. Aquatic Invasions, Volume 6, Issue 1: 17–31. doi: 10.3391/ai.2011.6.1.03

Mathiesen S S, Thyrring J, Hemmer-Hansen J, Berge J, Sukhotin A, Leopold P, Bekaert M, Sejr M K, Nielsen E E, 2017. Genetic diversity and connectivity within Mytilus spp. in the subarctic and Arctic. Evolutionary Applications 2017; 10: 39–55. DOI: 10.1111/eva.12415

Olesen J, Tendal O S, 2009. Amerikansk brakvandskrabbeart - ny krabbeart etableret i Danmark. Dyr I Natur Og Museum, 2009, Vol 2009, Issue 2, p. 26-28.

Rodriguez S R, Ojedal F P, Inestrosa N C, 1993. Settlement of benthic marine invertebrates. Mar.Ecol.Prog.Ser Vol 97: 193-207.1993.

Stramskaab M, BiałogrodzKaa J, 2015. Spatial and temporal variability of sea surface temperature in the Baltic Sea based on 32-years (1982–2013) of satellite data. Oceanologia. Volume 57, Issue 3, July–September 2015, Pages 223-235. https://doi.org/10.1016/j.oceano.2015.04.004.

Strandberg B, 2017. Vurdering af invasive arters forekomst og påvirkninger i danmark. Teknisk rapport fra DCE – Nationalt Center for Miljø og Energi. Nr. 96. Aarhus Universitet, Institut for Bioscience.

Stuer-Lauridsen F, Drillet G, Hansen F T, Saunders J, 2018. Same Risk Area: An area-based approach for the management of bioinvasion risks from ships' ballast water. Marine Policy. *Accepted*. DOI: 10.1016/j.marpol.2018.05.009.

Stuer-Lauridsen F, Hansen F T, Overgaard S B, 2016. Same Risk Area Concept.Procedure and Scientific Basis. Final report. By Litehauz Aps for ITERFERRY and Danish Nature Agency

Syvret M, FitzGerald A, Hoare P, 2008. Development of a Pacific Oyster Aquaculture Protocol for the UK. UK: Sea Fish Industry Authority.

Toonen R J, Pawlik J R, 2001. Foundations of gregariousness: a dispersal polymorphism among the planktonic larvae of a marine. Evolution, 55(12), 2001, pp. 2439-2454

Trebitz A S, Hoffman J C, Darling J A, Pilgrim E M, Kelly J R, Brown E A, Chadderton W L, Egan S P, Grey E K, Hashsham S A, Klymus K E, Mahon A R, Ram J L, Schultz M T, Stepien C A, Schardt J C, 2017. Early detection monitoring for aquatic non-indigenous species: Optimizing surveillance, incorporating advanced technologies, and identifying research needs. Journal of Environmental Management 202, pp 299-310

Valentine P C, Collie J S, Reid R N, Asch R G, Guida V G, Blackwood D S, 2007. The occurrence of the colonial ascidian *Didemnum sp.* on Georges Bank gravel habitat: Ecological observations and potential effects on groundfish and scallop fisheries. J. Exp. Mar. Biol. Ecol, 342:179-181.

Verween A, Vincx M, Degraer S, 2006. Growth patterns of *Mytilopsis leucophaeata*, an invasive biofouling bivalve in Europe. Biofouling 22 (4): 221 -231.

Vincent R, Ser-Giacomi E, López C, Hernández-García E, 2014. Hydrodynamic provinces and oceanic connectivity from a transport network help designing marine reserves. Geophysical Research Letters 41, 2883-2891 (2014). DOI: 10.1002/2014GL059540.

Verween A, Kerckhof F, Vincx M, Degraer S, 2006. First European record of the invasive brackish water clam *Rangia cuneate* (G.B. Sowerby I, 1831) (Mollusca: Bivalvia). Aquatic Invasions (2006) Volume 1, Issue 4: 198-203. DOI 10.3391/ai.2006.1.4.1

Warzocha J, Szymanek L, Witalis B, Wodzinowski T, 2015. The first report on the establishment and spread of the alien clam *Rangia cuneate* (Mactridae) in the Polish part of the Vistula Lagoon (southern Baltic). Oceanologia (2015), http://dx.doi.org/10.1016/j.oceano.2015.10.001

Wolff W J, 2005. Non-indigenous marine and estuarine species in the Netherlands. Zoologische Mededelingen 79 (1), 1e116

Wu, Y, 1988. Distribution and shell height-weight relation of *Rapana venosa* Valenciennes in the Laizhou Bay. Marine Science/Haiyang Kexue, 6: 39–40.

Appendix 1 Marine Invasive Species shortlist–Methodology and results

Appendix 1 can be found in a separate report (DTU Aqua Report no. 335a-2018).
The report can be downloaded from the list of research reports at aqua.dtu.dk/publications.

Appendix 2 Connectivity analysis—Methodology, results and interpretation

Appendix 2 can be found in a separate report (DTU Aqua Report no. 335b-2018).
The report can be downloaded from the list of research reports at aqua.dtu.dk/publications.

Appendix 3 Connectivity analysis—Additional results

Appendix 3 can be found in a separate report (DTU Aqua Report no. 335c-2018).
The report can be downloaded from the list of research reports at aqua.dtu.dk/publications.

DTU Aqua
National Institute of Aquatic Resources
Technical University of Denmark

Kemitorvet
2800 Kgs. Lyngby
Denmark
Tel: + 45 35 88 33 00
aqua@aqua.dtu.dk

www.aqua.dtu.dk